



PROJECT TITLE: Dynamic Response of a Semi-enclosed Sea to Atmospheric and Tidal Forcing.(Final Report)

PRINCIPAL INVESTIGATORS: Julio Candela / Carlos J. Lozano

INSTITUTION: Woods Hole Oceanographic Institution / Earth and Planetary Sciences , Harvard University  
ADDRESS: Woods Hole, MA 02543 / Cambridge, MA, 02138  
TELEPHONE (voice): (508) 457-2000 x2907 / (617) 495-9807  
TELEPHONE (fax): (508) 457-2181 / (617) 495-5192 E-MAIL: julio@mar.whoi.edu / lozano@alboran.harvard.edu  
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#### LONG TERM GOALS

To develop procedures that permit a quantitative description of the linear and weakly nonlinear barotropic and baroclinic response of a semi-enclosed sea with variable bottom topography to atmospheric forcings taking into account the presence of straits and dissipation. The whole formulation is in terms of modified shallow water equations in a rotating basin using an spectral approach.

We envision this formulation as a complement -as it has been in Meteorology- to eddy resolving modeling efforts. It is a complement in the sense that it permits us to identify and characterize basin response regimes and the relative influence of different forcings. These characterizations will aid in the interpretation of detailed models and in vis-à-vis observed behaviour in models and data will motivate further dynamical studies.

#### OBJECTIVE

The internal dynamics of a semi-enclosed sea is influenced by its thermohaline structure, atmospheric forcings, interactions with lateral boundaries, bottom topography and remote interactions transmitted through interconnecting straits. The construction of simple and accurate representations of the dynamical response of a semi-enclosed sea facilitates dynamical interpretation and it is conducive to robust data assimilation models for nowcast and forecast. Our specific objectives are: i) To develop and exploit practical and efficient barotropic/baroclinic spectral primitive equation models with data assimilation capabilities for ii) accurate simulations of the dynamical response of semi-enclosed seas to observed atmospheric and tidal forcings. iii) To conduct studies of dynamical processes and exercise assimilation schemes in the Mediterranean Sea and in the Gulf of Mexico-Caribbean Sea Basin.

#### APPROACH

The methodology is based on projecting the primitive equations onto a complete set of spatial functions defined over the basin, separating the velocity field into rotational and divergent contributions. The projection yields an infinite system of differential equations. The spectral model is a suitably truncated system of differential equations. An efficient time integration scheme is achieved with a basin mode representation; non-linear terms are computed in the physical space using the transform method. This methodology was implemented first for barotropic motions in semi-enclosed seas with "narrow" straits, i.e., the Mediterranean Sea. Additional physics were incorporated into the model as numerical and calibration issues were resolved through idealized cases, realistic model simulations using observed atmospheric and tidal forcings and comparisons with observed data. To explore inter-basin interactions we are using a Lagrangian function approach that adapts naturally to the spectral representation.

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## TASKS COMPLETED

1) A detailed analysis of the response of the Mediterranean Sea to observed atmospheric pressure (Candela and Lozano, 1994) has permitted a spectral characterization of the response and the identification of seasonal regimes using empirical modes. The model predictions of the barotropic transport across the Straits of Sicily can be used as a proxy for, so far, missing observations.

2) A robust estimate of the relative influence of the independent and co-oscillating M2 tide in the Mediterranean has been established (Lozano and Candela, 1995). An accurate inclusion of ocean tide load effects, due to both the tide outside of the basin, and the local tide is achieved in a simple and economic way in the spectral model. For the M2 tide in the Mediterranean the tide load effect is of the same order of magnitude as frictional dissipation. Our finding suggests that simple parameterizations of this effect, used often in global tidal models, need to be re-examined.

3) Applied the barotropic spectral model response of the Mediterranean Sea to observed atmospheric forcing to correct Topex/Poseidon altimetric data. Our model corrections differ substantially from the application of a direct inverse barometer response correction, as is commonly performed to correct altimetric data in the open Ocean. However, using as a measure of "goodness" the reduction of the variance of the altimetric data when the corrections are applied is ambiguous, showing a tendency for our model to do better in the Eastern Mediterranean and the inverse barometer to do better in the Western Basin. We are now in the process of calibrating our model with recently acquired data of flows through the Strait of Gibraltar and sea level inside the Mediterranean, and also determining a more objective measure of "goodness" of correction rather than the simple reduction of the variance of the altimetric data.

4) The barotropic model for the Gulf of Mexico-Caribbean Sea system has been implemented with the incorporation of specific open boundary irrotational and rotational functions to open up the system to the Atlantic Ocean through 15 "straits". An early description of the procedure and preliminary results were presented at the AGU Chapman Conference "Circulation of the Intra-Americas Sea", January 22-26, 1995, at La Parguera, Lajas, Puerto Rico. The construction of the system's normal modes and their application to investigate the response of the system to specific forcings has been studied (Sheinbaum, Zavala and Candela, 1997).

5) Implement the use of specifically constructed basis functions in a region to simultaneously analyze ship-board ADCP currents and hydrographic data. This procedure was applied for a two week data set from the Alboran Sea, i.e. the entrance to the Mediterranean Sea, where the tidal and subinertial fields at different levels were successfully extracted from the data set. A paper is being prepared on this material. Also it has been applied to the extensive ADCP data set being collected over Georges Bank during the ongoing GLOBEC Program. Preliminary results were presented at the Ocean Science Meeting in San Diego, CA, Candela, J. and C.N. Flagg, 1996. Large-scale current and acoustic backscatter intensity patterns on Georges Bank from ship-board ADCP data. 1996 Ocean Science Meeting, San Diego, California, February 12-16, OS156, (abstract).

6) The use of irrotational modes to investigate seiche activities in limited areas with application to the Strait of Sicily. In sea level observations across the Strait of Sicily, which were obtained through another ONR sponsored program, the presence of a 30 to 50 minute period, strait wide and year round persistent modes have been identified. An investigation of the possible forcing mechanisms has been performed. Results were presented at a meeting in Canada: Candela J., 1996. The "Mad-Sea" Phenomenon in the Strait of Sicily. Coastal Zone Canada '96, Rimouski, Quebec, Canada. 11-17 August, 1996, 37 pp., (abstract). A complete publication is now being written.

## PUBLICATIONS

- Candela, Julio and Carlos J. Lozano, 1994. Barotropic response of the western Mediterranean to observed atmospheric pressure forcing. In: The Seasonal and Interannual Variability of the Western Mediterranean Sea. P.~E. La~Violette, editor, Coastal and Estuarine Studies, 46, 325--359, American Geophysical Union.
- Lozano, Carlos J., and Julio Candela, 1995. The M2 tide in the Mediterranean Sea: Dynamical analysis and data assimilation. *Oceanologica Acta*, Vol. 18, N 4, 419-441.
- Sheimbaun, J., J. Zavala y J. Candela. Modelacion numerica del Golfo de Mexico y Mar Caribe. Monografia sobre Oceanografia Fisica. Union Geofisica Mexicana (in press).

## PRESENTATIONS

- Candela, J. and C. J. Lozano, 1992. The barotropic response of the Mediterranean Sea to atmospheric forcing. EOS, Transactions, American Geophysical Union, 73(43), 89, (abstract).
- Candela, J., C. J. Lozano and J. Sheinbaum, 1995. On the barotropic response of the Gulf of Mexico-Caribbean Sea system: Sensitivity to atmospheric forcings and interactions with the Atlantic Ocean. Circulation of the Intra-Americas Sea, Chapman Conference, American Geophysical Union, La Parguera, Lajas, Puerto Rico. January 22-26, 1995, 18, (abstract).
- Candela, J. and C.N. Flagg, 1996. Large-scale current and acoustic backscatter intensity patterns on Georges Bank from ship-board ADCP data. 1996 Ocean Science Meeting, San Diego, California, February 12-16, OS156, (abstract).
- Candela, J., 1996. The "Mad-Sea" Phenomenon in the Strait of Sicily. Coastal Zone Canada '96, Rimouski, Quebec, Canada. 11-17 August, 1996, 37 pp., (abstract).